CHAPTER 8

Superstructure and Deckhouse Design

The Purpose of a Superstructure

1 This chapter discusses the requirements for superstructures or deckhouses on warships, and methods of design and analysis. The advantages and disadvantages of difference configurations and materials are considered, although mainly for vessels of destroyer and frigate size; the principles will, however, apply to any vessel. At the end of the chapter a short worked example is included to illustrate the steps needed for design of a deckhouse on the hull structure already designed in Chapter 7.

2 To clarify the definitions, the terms superstructure and deckhouse are interchangeable, but there is a tendency to call structures above the upper strength deck on merchant ships ‘deckhouses’, while the structure above 1 deck on warships is generally termed ‘superstructure’. Consequently, deckhouses may be taken to be smaller and less efficient in carrying longitudinal load than superstructures although there is no real justification for the distinction. To avoid confusion Lloyd’s Rules call all structures above the strength deck ‘erections’; this chapter will, however, use the word ‘superstructure’ whatever the configuration. A further problem of definition sometimes exists; when a ship has a long, full width superstructure it may be considered to be part of the hull and the top nominated as the upper deck (or 1 deck). Further guidance on whether the top of the superstructure may also be considered as the main strength deck is given in paragraph 28. For practical purposes it will be assumed in this publication that if a block of structure reaches either end of the ship (usually the bow) then it is treated as part of the hull and the step down at the other end is treated as a break of forecastle (Chapter 12); if it steps down at both ends then it is superstructure.

3 An ideal beam structure would have no load bearing attachments above the strength deck so as to avoid complex load paths and consequent stress concentrations. However, a practical layout will require a superstructure to provide protection from the sea and weather for the few items that have to be on the upper deck of a ship. Additionally, it will give height to the bridge and can provide stiff structure on which conveniently to step masts, weapons and sensors. Where a mast is excited as part of an aerial system the superstructure in the vicinity may also be used to extend the length of the aerial dipole vertically (and this use may inhibit changes to the superstructure configuration at a later stage in the design or during the ship’s life).

4 *Table 8.1* lists compartments which are of necessity in the superstructure and gives approximate deck areas for a typical frigate, totalling about 300 m^2 on 1 deck and 120 m^2

(excluding the hangar upper level) at 01 and 02 deck levels. If 20% is added for passageways and lobbies the requirement is a plan area of 360 m^2 which can be satisfied by a full width structure of 15 m x 24 m or a structure inset from the ship's side of say 10 m x 36 m. The length is clearly considerably less than that of a frigate hull (the hull in the example in Chapter 7 has a length of 120 m) and so there is no need, from the point of view of provision of deck area, for an extensive superstructure on this type of ship. On smaller ships the superstructure may take up a more significant proportion of the upper deck, while on larger ships other considerations, such as the distribution of weapons and their supports, or aircraft arrangements, are likely to control superstructure layout. There may also be occasions when the volume of the structure below 1 deck is restricted either because of limitations to the overall dimensions of the ship for physical reasons or due to cost constraints, or because an existing hull is being converted to another use, and the superstructure may then have to be larger to accommodate spaces which could otherwise be sited within the main hull envelope. Note that for some vessels a minimum length of superstructure relative to upper deck length may be the governing parameter, but the same general principles will still apply.

TABLE 8.1
Minimum Space Required in a Frigate Superstructure

02 Deck	*Area* (m^2)
Bridge	45
Weapons office(s)	36
Chart house	9
Navigator's cabin	9
Satellite communications office	8
Flag locker	6
01 Deck	*Area* (m^2)
Commanding Officer's suite	40
Radar office	25
Weapons offices	50
1 Deck	*Area* (m^2)
NBC cleansing stations	16
Battery charging room	8
Deck stores	8
Hangar (will extend into 01 deck)	200
Uptake and downtake spaces	65

Superstructure Loading

5 Before considering design problems it is necessary to discuss the various loads on a superstructure, which divide conveniently into four categories:

a. Loads transmitted from the ship's hull.

b. Loads due directly to wind and waves.

c. Loads due to gravitational and inertial effects on equipment.

d. Loads due to weapon effects (own and enemy weapons).

6 Loads transmitted from the ship's hull are due primarily to vertical bending. As the hull bends a strain is induced in the upper deck as the top flange of the beam, and for a welded or otherwise 100% efficient joint an equal strain must exist at the bottom of the superstructure sides. The superstructure, in consequence, tries to bend in the opposite direction as indicated in *Figure 8.1*. If the elastic moduli of the main hull and the superstructure are the same, very high vertical loads must then be developed at the interface to enforce compatibility of curvature, especially near the ends and in the mid-length region. This is the main reason for the rules for structural continuity and alignment laid down in Chapter 6 which are intended to ensure that the structure can be designed to withstand the high stresses without undue risk of fatigue failure. These compatibility loads will exist whatever the extent of the superstructure but are greater for longer lengths and reach a maximum when the top of the superstructure at its mid-length is fully effective as part of the hull beam (and when the mean stress in the top deck can be derived from the simple beam equations). As the superstructure length increases beyond this point (unless the superstructure is positioned significantly away from amidships) the loads enforcing compatibility will decline because the ends of the superstructure are getting nearer to the ends of the ship, where the hull stresses are lower.

7 The effectiveness of the superstructure, mentioned above, is defined in more detail in paragraph 28, but the term refers to the capability of the superstructure to take primary longitudinal bending loads as part of the hull girder. A long, wide superstructure, which is well integrated and with a number of supporting transverse bulkheads, will be highly effective, while a small superstructure with a minimum of support will be relatively ineffective. All superstructure configurations will, however, take some load from the hull, and one principal requirement of superstructure design is to balance the scantlings between hull and superstructure so that neither is overloaded or significantly underloaded.

8 Loads due to waves and wind, the former known as 'green sea loading', are described in Chapters 3 and 4 and are usually approximated to by static pressures. There are considerable differences between stated requirements, for example Classification Society rules vary by a large factor as described by Hansen (1982). The recommended pressures given in this book are roughly mid-way through the range and are less elaborately presented than the Classification Societies'

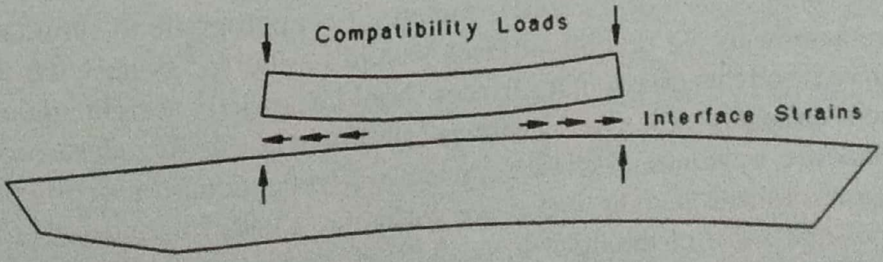

Figure 8.1 Hull-Superstructure Interaction

being derived from experience principally from frigate and destroyer sized ships. There is very little trials data reported and none which can be found in open literature, so the figures given in Chapter 3, which are based on limited trials on weapon equipment and on a knowledge of minor structural failures, should be regarded as a guide to the *maximum* equivalent static pressure to be expected, and no further load factors are necessary.

9 Green sea loads on the lower tiers of superstructure will always predominate over wind loading. Wind loads may need to be considered at higher levels; guidance on the estimation of wind loads is given in Chapter 4.

10 Gravitational loads are due simply to the static mass of equipment mounted on, or in, the superstructure, while inertial loads are the result of accelerations of these masses due to ship motion. Generally small masses will not cause dominating loads and large masses will require special support structure which is additional to that of the superstructure. On the whole, therefore, it is unlikely that gravitational and inertial loads will drive the structural design of the overall superstructure but care should be taken in the positioning of moderately heavy items to ensure that there is adequately stiff support structure, for example they should not be positioned in the middle of a large panel so that all the load is taken in bending. Guidance on estimating inertial loads is again given in Chapter 4.

11 Loads due to weapon effects derive from both the ship's own weapons as well as those of the enemy. Pressures from gun blast or missile efflux may be approximated to by the methods of Chapter 4 which, while fairly crude, give acceptable results. The loads, which should desirably be resisted during attacks from enemy weapons, will depend to a great extent on the operational requirements for the ship. It is difficult to make allowance for more than the superficial effects of blast and fragments from a near miss, as the effect of a modern penetrating missile is usually devastating. Nevertheless, it will be desirable to give some protection to high value equipments and the use of modern ballistic protection should be considered. Protection can be obtained by using greater thicknesses of steel but, in this case, care must be taken not to create local stress concentrations where the ballistic protection is attached to conventional structure (see also paragraph 27). Loads due to nuclear air blast, where they are required to be withstood, may be estimated from the method in Chapter 4.

Radar Cross Section

12 Detailed instructions for the reduction of radar cross section in surface ships are given in MOD publications which are not readily available, and so because radar cross section is strongly influenced by the configuration of the superstructure, it is appropriate to summarise them here. The principal requirements are that all surfaces should be flat (or as near flat as possible and certainly not curved) and that no two flat surfaces should be exactly at right angles to each other. The reason for this arrangement is to reduce the possibility of an enemy radar being able to follow a 'flash' reflection from a cylindrical surface or a focussed reflection from a corner reflector. In the latter context three surfaces at right angles are particularly bad. In almost all relevant tactical situations the incident angle of the radar beam will not be more than a few degrees above the horizontal, so it is the near vertical parts of the structure which must receive the most attention.

13 Means of reduction of radar cross section may be summarised by five basic rules:

a. Avoid curved surfaces and re-entrant trihedral and dihedral corners.

b. Use flat plates facing in one of four principal azimuth direction (0, 90, 180, 270 degrees relative to centreline) or upwards.

c. Cant vertical plates a few degrees (about 6°, which must be constant throughout a particular ship) away from the vertical; either tumblehome or flare is acceptable.

d. Avoid sharp salient corners at the meeting of two flat plates; about 20 mm radius should be the aim, as far as it is practicable.

e. Avoid repeated or complex structures such as louvres or latticework.

Requirements of Superstructure Design

14 The above paragraphs, together with the needs of basic naval architecture, lead to the following superstructure design requirements:

a. To provide adequate volume outside the main hull for the ship to meet the operational specification (which may include an overflow from the main hull if overall dimensions are constrained).

b. To provide adequate deck space and height for weapons and sensors.

c. To lead to an acceptable vertical centre of gravity for the whole ship, while keeping weight and cost within acceptable bounds.

d. To have good through life structural reliability, requiring minimum maintenance.

e. To contribute to the primary strength of the ship if appropriate.

f. To be adequately strong to withstand all secondary loads implied by the operational requirement.

g. To provide adequate rigidity for support to weapons, sensors and masts.

h. To have a minimum radar cross section.

i. To provide ballistic protection where necessary.

15 These requirements are not all compatible, in particular a. and b. may lead to a voluminous and high structure; c. requires a low but not necessarily small structure; d, f. and g. require a stiff well integrated structure with a minimum of discontinuities and additionally e. would require such a structure to be at least half the ship's length; h. requires minimum size in all dimensions and imposes constraints on shape and layout. Angling the vertical surfaces to reduce radar cross section will introduce other incompatibilities, for example angling the superstructure sides inwards leads to loss of volume or the need for more deck area, while flare in the hull provides more deck space above as well as volume, although the latter may not be readily usable.

16 Some styles that have evolved in the recent past are:

- Long and fairly low, as in LEANDER and COUNTY Class vessels.
- Minimum size, as in the CASTLE Class.
- Fairly voluminous but discontinuous, as in the DUKE Class.

Variations or combinations of these styles tend to have worse characteristics, for example the USN FFG7 Class, which has a long, high superstructure with discontinuities, and is constructed of aluminium, suffers from frequent fatigue failures and consequent high maintenance costs. Before the structure is finalised it is essential that the basic naval architectural requirements a, b. and c. in paragraph 14 are satisfied, although this may beg the question as to whether the main hull could have been larger and the superstructure smaller. However, of the three styles above, the first can satisfy all the requirements except h. for minimum radar cross section (RCS), the second can satisfy all the requirements without exception, as can the third except that great care is needed to meet both d. for reliability and h. for RCS.

17 The subjective conclusion is that a minimum size, structurally ineffective, superstructure, enclosing only those spaces listed in *Table 8.1*, will be the best design solution, satisfying all the requirements with least effort and risk. However, if there is some constraint on the hull dimensions which restricts free allocation of space within the hull, then the long, low, structurally effective superstructure is likely to be the most reliable in service, as it is easier to integrate the structure with the hull beneath and can also make possible small reductions in hull scantlings by increasing the effective depth of the hull girder. There will be some sacrifice in increased RCS but with care it need not be large.

18 Within these configurations some scope exists for adjustments to width and length. To be fully effective structurally a superstructure should be at least half the length of the hull and of full width, at least in the midship region. However, the sides may be inset provided that there is adequate continuity of longitudinal structure beneath, for example utilising the inboard bulkheads of side passageways. It is always important that the side structure contains no fore and aft discontinuities as these will lead to stress concentrations in an area where average stresses must inevitably be high. Conversely, as the ends will suffer high vertical stresses (see paragraph 6) there must be no vertical discontinuities, including holes, near the ends. Examples of good and bad arrangements are illustrated in *Figure 8.2*.

19 For a minimum size superstructure the block (or each block if more than one) should be not more than one tenth of the ship length long and may be inset from the ship's side, both to

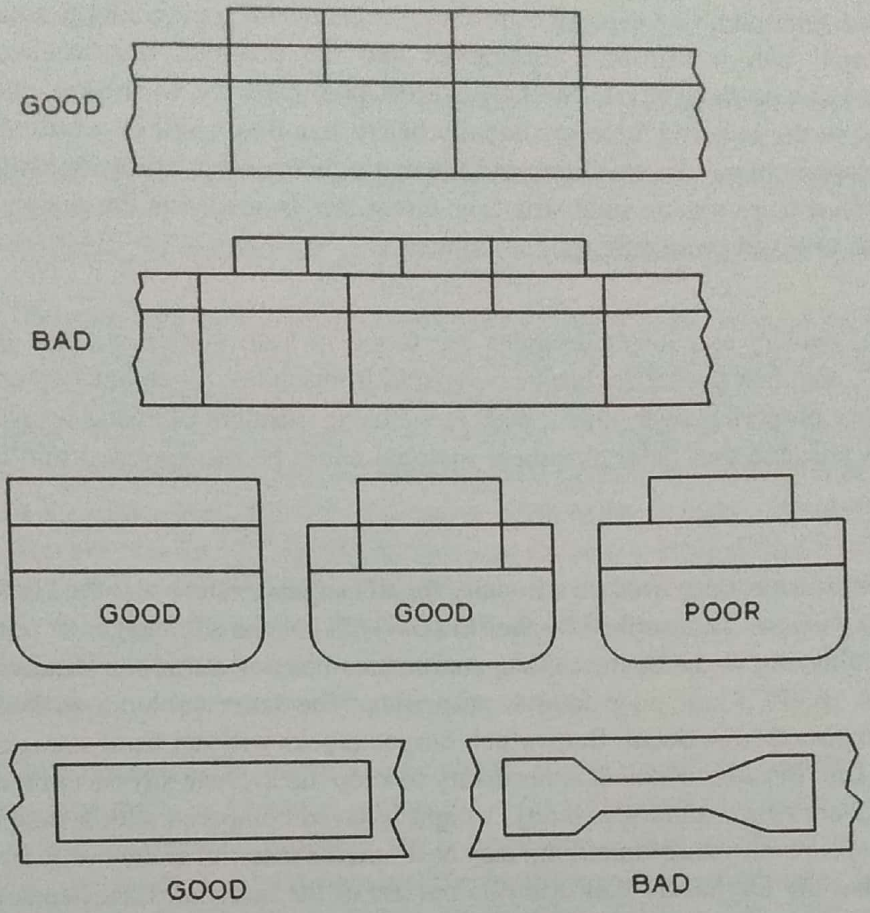

Figure 8.2 Good and Bad Superstructure Arrangements

reduce the transmitted stresses and to provide access along the upper deck. Continuity is still important but scantlings may be fairly light as the principal loads will be due to lateral pressure. The area requirements of *Table 8.1* imply that three blocks should be sufficient on a ship of that size, or two if they are near the ends of the ship where the L/10 rule may be relaxed. The three block arrangement should have a separation between blocks of at least L/10 to minimise structural interference and to simplify integration with the bulkheads beneath; this separation and integration may be difficult to achieve but it is important if later fatigue and maintenance problems are to be avoided. The smallest possible number of superstructure blocks should always be the aim.

Materials

20 Implicit in the foregoing discussion is that both the hull and superstructure are built of steel. Certainly all the conflicting requirements can be satisfied using steel, and in most cases steel will be the first choice for superstructure material. The particular disadvantages of steel in this context are its weight and its having the same elastic modulus as the hull material (assuming that that is also of steel) leading to the problems described in paragraph 6. Weight should not be a problem if the minimum size superstructure style is followed, but for a large superstructure on a relatively small hull it can pose difficulties and the potential disadvantages of such an arrangement must be recognised. The high elastic modulus leads to stresses at the interface as high as those in the hull and therefore equally heavy scantlings will be required; indeed, at the ends of the superstructure its existence and the consequent compatibility loads leads to heavier scantlings than if there was no superstructure. Great care is needed in the design of these highly stressed areas to avoid premature fatigue failures.

21 Lower density and lower modulus are found in both aluminium and fibre reinforced plastic (FRP), and their properties can be compared from figures given in Chapter 5. FRP can be tailored to have properties over quite a wide range using different fibre and weave combinations and it is also possible that radar absorbent material could be incorporated into the laminate to reduce RCS.

22 Aluminium has been used occasionally for RN superstructure and the USN has used it is very many ship classes as described by Sielski (1987). It has the advantages of relative lightness and low modulus, but in the context of superstructures has two particular disadvantages, a low melting point (650°C) and poor fatigue properties. The latter problem makes it especially susceptible to poor design detail, from which fatigue cracks will run from stress concentrations very early in life. Because of this it is necessary to keep the average stresses low with the result that scantlings are heavy and little, if any, weight is saved compared with a steel structure. For small blocks of superstructure aluminium may be a suitable material as the cyclic stress range will then be low, but the fire hazard may still rule out use of the material. Care needs to be taken to avoid electrolytic corrosion when attaching aluminium to steel and guidance is given, inter alia, in NES155 Part 1.

23 FRP has not, so far, been used as a superstructure material on a steel ship. The current form of construction, as used in MCM vessels, is labour intensive and it would be difficult to build a cost effective superstructure produced in the same way as for MCM vessel hulls. However, other forms of construction are feasible and the advantages of FRP in a superstructure are considerable, as discussed by Smith and Chalmers (1987). The difference in elastic modulus effectively decouples the superstructure from the hull, that is, the induced strains in the superstructure lead to very low stresses and the hull is hardly affected by superstructure response. In consequence the need for continuity of structure is much reduced and the layout of both the hull and superstructure is much simplified. Smith and Chalmers (1987) show that it is possible, in fact, to design an FRP superstructure on a steel hull without supporting transverse bulkheads under the ends.

24 Additional advantages of FRP are:

a. Good fatigue properties making it tolerant of discontinuities.

b. Ease of creating the shape (especially flatness) required for RCS.

c. Good durability and low maintenance costs.

which are offset by disadvantages:

d. Electromagnetic radiation transparency, both to internal emissions and radar.

e. Relatively high cost (although this is being reduced by better production engineering).

f. Low stiffness for support of equipment and for resistance to lateral pressure.

The problem of EM transparency to internal emissions has largely been solved in the construction of MCM vessels but the process requires flame spraying zinc on to the inside surface of the structure after it is completed. As such it is disruptive to outfit procedures and is particularly difficult to integrate with modern modular pre-outfitting. Furthermore, the efficacy of metal spraying in reducing radar cross section has not been fully investigated. The cost of high quality FRP is rapidly being reduced as its use in other engineering fields spreads, and a project aimed at minimising production cost for FRP superstructure is described by Hannah and Chalmers (1988) where it is shown that realistic FRP structures can be made lighter than steel and with construction cost less than aluminium. Through life costs, taking into account the very low maintenance needs of FRP, should lead to a structure which, overall, is cheaper than steel, but so far there is insufficient evidence to confirm this expectation.

25 Unless there is extensive internal subdivision, the low stiffness of FRP may pose a problem in supporting masts and weapon equipment and in resisting lateral loads, but this may be overcome by incorporating stiff (probably steel) transverse frames as shown by Hannah and Chalmers (1988). The structure then becomes stiffer in withstanding equipment and environmental loads while retaining its advantage of low longitudinal stiffness. The FRP panels can be adequately stiff to withstand all racking loads, but the steel frame does increase the weight somewhat above the theoretical minimum if only FRP is used. However, a fully FRP structure would be very bulky to withstand the lateral loads.

26 Effects of fire on FRP are discussed in Chapter 5 and are less significant than on aluminium, so fire performance need not be a disadvantage. Conventional FRP loses its strength at about 200°C, but it conducts heat so slowly that loss of strength is very localised and spread of fire is limited. The use of phenolic resin, as discussed in Chapter 5, could also improve fire performance at the cost of a small (about 10%) reduction in strength and stiffness below polyester resin.

27 Ballistic protection is usually only applied to magazines or other high risk compartments in RN ships, but because of the difficulty of handling modern weapons from deep magazines there is an increasing tendency to fit magazines in the superstructure where they are very vulnerable. There will, therefore, be a frequent requirement to protect this exposed structure. Composite materials, including woven aramid fibre fabrics and ceramics, may be used (and indeed are used in military aircraft and some vehicles), but are very expensive - perhaps in the order of £1000/m^2. High strength weldable steels are also in existence and again are used in military vehicles but there is some doubt over their weldability in shipyard conditions. Variations on FRP, including high strength fibres in the lay-up, may also be effective and merit investigation. Steel honeycomb materials have been used in the US Navy to reduce weight as well as to provide protection, but they are very expensive and are likely to be difficult to justify in terms of value for money.

Superstructure Efficiency

28 The terms superstructure efficiency and effectiveness have been used but not yet defined. The **effectiveness** of a superstructure is a qualitative measure of the extent to which it contributes to the longitudinal strength of the hull. As such a superstructure may initially be assumed to be ineffective so that the hull girder is designed to take all the wave bending loads. However, no superstructure is totally ineffective as some load is always transmitted from the hull and so the final design of the structure must allow for the interaction. Alternatively, a superstructure may be assumed initially to be fully effective and so to form part of the hull girder at least in the midship region; this assumption will only be valid for the long low style of superstructure discussed in paragraphs 17 and 18. Again, in the final design a check must be made on the validity of the initial assumptions along the whole length of the superstructure.

29 The **efficiency** (η_{ss}) of the superstructure is a more precise measure and is used to estimate the stress at the top of the structure in relation to what it would be if the simple beam equation was valid. It can be defined in a number of ways, but the most commonly used definition is that due to Caldwell (1957) and is simply the ratio between the actual stress at the top of the superstructure at any transverse section to the stress that would exist if plane sections remained plain and there was a linear distribution of strain over the full depth of the section, as illustrated in *Figure 8.3* which also assumes a constant elastic modulus over the section. In practice, superstructure efficiency is most sensitive to the ratios of superstructure length (L_s) to height (d_s) and breadth (B_s) provided that there is sufficient support along the length. As a rough rule if $L_s/(d_s + B_s)$ is greater than 6 then the efficiency should be at least 90% whilst if it is greater than about 4 then the efficiency will be a little less but the superstructure may still be treated as effective with the hull girder.

30 The different stresses in *Figure 8.3* are defined as follows where η_{ss} is the superstructure efficiency:

(8.1a) $$\sigma_o = Mz_o/I_o$$

(8.1b) $$\sigma_{100} = Mz_{100}/I_{100}$$

(8.1c) $$\sigma_r = \sigma_o - \eta_{ss}(\sigma_o - \sigma_{100})$$

(8.1d) $$\sigma_{br} = \sigma_{bo} - \eta_{ss}(\sigma_{bo} - \sigma_{b100})$$

(8.1e) $$\sigma_{d100} = M(z_{100} + d_s)/I_{100}$$

(8.1f) $$\sigma_d = \eta_{ss}\,\sigma_{d100}$$

where M = Design bending moment
I_o = Second moment of hull only about NA
I_{100} = Second moment of hull and 100% of superstructure about NA.

Openings in the superstructure sides and deck that are not adequately compensated for are to be deducted before the calculations for neutral axes and second moments are carried out. Where

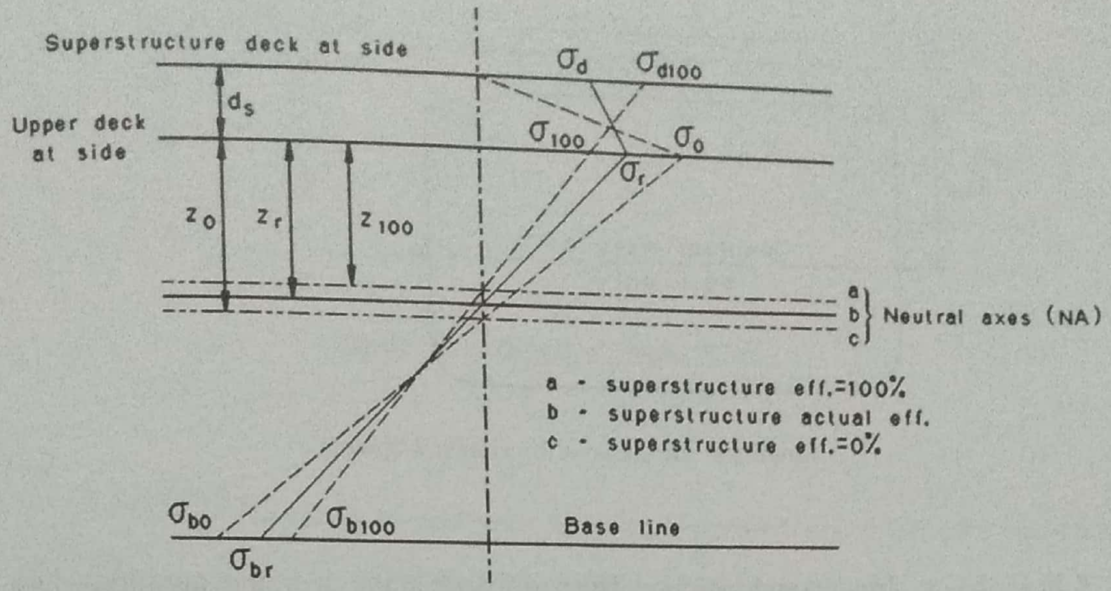

Figure 8.3 Stress Distribution Across Section - Different Superstructure Efficiencies

materials with a different modulus of elasticity E_{ss} are used in the superstructure, then the area of the material is to be multiplied by the ratio E_{ss}/E in the calculations of z_{100} and I_{100}.

31 To estimate the value of η_{ss} it is necessary to know the values of the parameters d_{na}/D_{na}, A_s/A_h and t_s, where d_{na} and D_{na} are defined in *Figure 8.4* (noting that the dimensions are measured from the intersection point R) and

A_s = Area of effective longitudinal material in the lowest tier of the superstructure
A_h = Area of the effective longitudinal material in the hull at the same section
and t_s = Thickness of superstructure side plating (after deduction of rolling allowance).

At the preliminary stages of design when there is insufficient information for a rigorous calculation it is possible to estimate the first two parameters from the following approximate equations derived from unpublished MOD work:

$$d_{na}/D_{na} = d_s\,(B_s^* + d_s)/\{D_{na}\,(B_s^* + 2d_s)\} \tag{8.2}$$

$$A_s/A_h = \eta_{ss}\,(B_s^* + 2d_s)/\{\gamma_1 + \gamma_2 + B^* + 2(D - T)\} \tag{8.3}$$

where

$$\gamma_1^2 = 4T^2\,(1 - C_a)^2 + C_a^2\,B^2 \tag{8.3a}$$

$$\gamma_2^2 = 4T^2\,C_a^2 + B^2\,(1 - C_a)^2 \tag{8.3b}$$

$$C_a = \textit{Area Coefficient} = \textit{Submerged Area at Section/BT}$$

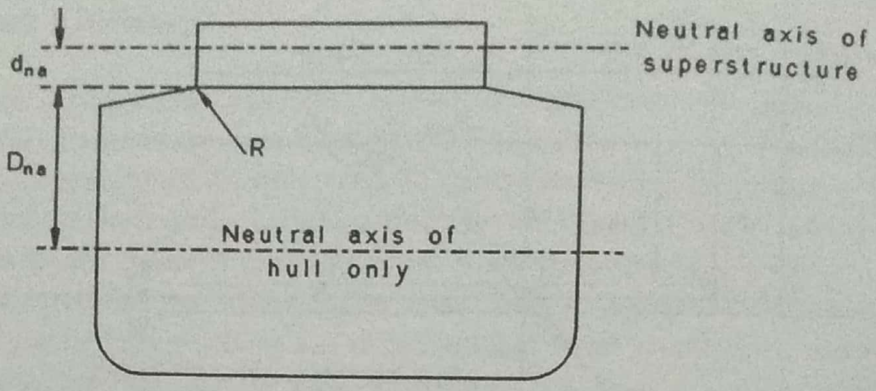

Figure 8.4 Definition of Neutral Axis Spacing

and B, T, D are beam, draught and moulded depth to 1 deck at the section in question while B_s is the breadth of the superstructure as shown in Figure 8.5. B* and B_s* are the beam and superstructure breadth reduced by the width of any major holes penetrating 1 and 01 deck. The ratios d_{na}/D_{na} and A_s/A_h can also be used to estimate values of z_{100} and I_{100} for input to equation 8.1 as described later in paragraph 64. There is no simple way to estimate the superstructure side thickness and it must be guessed from a knowledge of existing ships at the preliminary design stage.

32 The procedure for estimating η_{ss} is as follows, based on a method presented by Lloyd's Register in their rules of 1976 which itself was derived from Caldwell (1957). The current Lloyd's Rules do not specify any method, leaving it to the designer to calculate efficiency by whatever means he has available and then submitting the calculation to Lloyd's for approval. The method is, however, the most usable of those that have been published and, as presented here, has been modified slightly to be more representative of warship configurations. A particular difference from merchant ship rules is that no allowance should be made for any tier of superstructure above 01 deck. In the unlikely event of 02 deck being sufficiently extensive to be considered effective, that is probably more than 60% of the length of 01 deck, then it will be necessary to have recourse to the source reference documents, otherwise tiers above 01 deck need only be designed to withstand lateral load.

33 It is first necessary to calculate from equation 8.4 the flexibility factor ψ for the deck on which the superstructure stands:

$$\psi = 1.2 \times 10^4 KC^2 (t_s E_{ss} / d_s E) \tag{8.4}$$

where C is a constant depending on the transverse configuration as indicated in *Figure 8.5*, that is if the structure is as *Figure 8.5(a)* then $C = 1 - (B_s/B)^2$, if it is like *Figure 8.5(b)* then $C = (s_3/B)\{1 - (s/s_3)^2\}$ where s is whichever is the greater of s_1 and s_2, and if it is as *Figure 8.5(c)* then $C = 1 - (B_s/s_4)^2$. The continuous longitudinal bulkheads indicated in *Figure 8.5* must extend at least 3 m beyond both ends of the superstructure but need not be the full depth of the hull. Note that for a full width superstructure C is always zero.

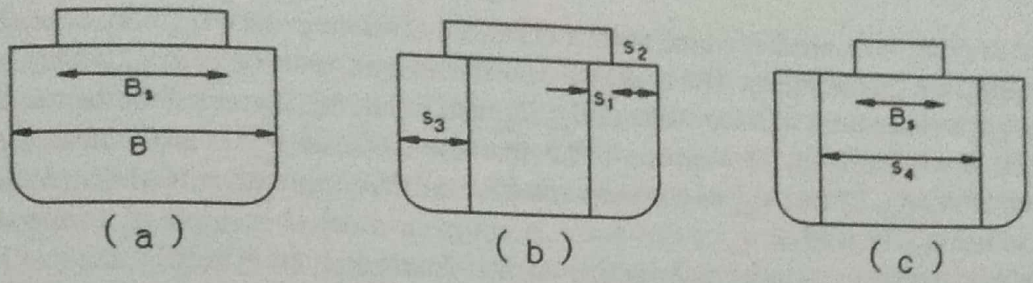

Figure 8.5 Definition of Breadth Terms

TABLE 8.2
Values of K for Equation 8.4

No. of Transverse Bulkheads in the Hull under the Superstructure	K	
	(a)	(b)
0	-	300.0
1	0.0	175.0
2	75.0	100.0
3	45.0	58.0
4	27.1	38.0
5	18.3	27.5
6	13.3	19.8
7	9.8	14.2
8	7.2	10.4
9	5.2	7.6
10	4.0	4.9

34 The value of K in equation 8.4 can be found from *Table 8.2* depending on the number of transverse bulkheads beneath the superstructure; in this context a transverse bulkhead must extend across the full width of the hull and downwards at least one deck height. Column (a) should be used if there are main transverse bulkheads under both ends of the superstructure and column (b) if main transverse bulkheads are not situated under the ends; if there is a bulkhead under one end then the average of the two columns should be used. Note that the value of K is independent of the longitudinal position of the section through the superstructure under consideration.

35 The basic superstructure efficiency η_{so} can then be found from data sheet 18.41 using the value of ψ from equation 8.4 and the superstructure length/height ratio L_s/d_s where the value of L_s is twice the distance from the section in question to the nearest end of the superstructure. The value of η_{so} obtained from data sheet 18.41 assumes standard values for other parameters which are $B_s/d_s = 5$, $d_{na}/D_{ba} = 0.35$ and $A_sE_{ss}/A_hE = 0.1$. The efficiency then has to be corrected for the actual values of the parameters using data sheets 18.42 to 18.44 as follows.

36 Enter data sheet 18.42 at 5 on the horizontal scale and locate the point corresponding to an efficiency of η_{so}; construct a line following the direction of the curved lines on the sheet until the true value of B_s/d_s is reached at which point a corrected efficiency value η_{s1} may be read off (an example is shown on the sheet). The next two data sheets are then used in exactly the same way obtaining η_{s2} corrected for the true value of d_{na}/D_{na} and finally η_{ss} corrected for the true value of A_sE_{ss}/A_hE. It will be seen from equation 8.3 that the value of η_{ss} is required in the initial estimation of A_s/A_h; in fact η_{ss} is not very sensitive to this ratio and it is sufficient as a first estimate to use η_{s2} instead of η_{ss} at this point. A complete worked example of a superstructure efficiency calculation is included later in this chapter (paragraph 60 et seq).

37 Having found the superstructure efficiency at all relevant sections it is then a simple matter to use *Figure 8.3* and equation 8.1 to calculate the stress distribution across each section (remembering to take account of the different elastic modulus if there is a different material) and in particular to find the longitudinal stress distribution in the superstructure deck. The deck structure may then be designed in the same way as for decks in the hull, as described in Chapter 7. The *longitudinal* stress in the sides may also be found in this way but, especially near the ends, does not dominate the structural design.

38 It will also be necessary to reiterate the design of the hull at this stage. If the superstructure was originally assumed ineffective then the hull stresses will be reduced, but unless the superstructure has grown unexpectedly large it will not usually be worth changing the hull design and the reduced stresses may be taken as a further safety margin. If the superstructure was originally assumed effective then the actual efficiency and stress distribution must be compared with that originally assumed and the hull scantlings increased (or reduced) if appropriate.

Design and Analysis

39 The analysis of the complex interactions between a hull and superstructure has exercised many researchers over past years. It is difficult to estimate the loads in the superstructure at early stages in design to enable the structure to be synthesised and even when the structure is designed it is difficult to analyse it accurately. There are a number of possible theories, for example Johnson (1957) assumes the superstructure to be a beam on an elastic foundation and follows the theory of Timoshenko. In particular, he assumed only two bulkheads underneath, one at each end, and varied the deck stiffness. He noted that for low deck stiffness the entire superstructure may deflect in the opposite curvature to that of the hull, imposing very large out-of-plane strains in the deck. This simple model points to the vital importance of transverse support to the superstructure at a number of points along the length, and especially at the ends.

40 Any ‘slip’ in the connection between the superstructure and the main hull will reduce the longitudinal strain in the superstructure. Clearly if the joint is welded then the slip will be zero, but rivetted or bolted connections may deform and the extent of the deformation needs to be estimated before the design can be completed. The shear characteristics of these connections have been quantified by Flint (1955) who has shown that the maximum shear strain near the ends may be significantly reduced by slip.

41 Caldwell (1957) proposes a method similar to Johnson (1957) but different in detail in that shear lag effects are accounted for in the sides and top of a single tier superstructure together with shear slip at the interface with the hull. The method assumes a uniform deck stiffness and cannot allow for intermediate bulkheads. This method was extended by Lloyd's Register to produce the method described above (paragraph 31 et seq) for estimation of superstructure efficiency.

42 Chapman (1957) considers two beam connected at a common elastic foundation and satisfying longitudinal compatibility at the interface. The differential equations for bending behaviour of each beam are expressed in finite difference form and solved numerically to give displacements at discrete points. Variations in sectional properties and foundation modulus can, therefore, be incorporated as well as the effect of a number of supporting bulkheads. However, all shear lag effects are ignored and the solutions are not valid close to the ends where equilibrium has to be maintained by point forces.

43 More recently Schade (1966) introduced a two-beam model which takes account of shear lag in the strength deck and shearing deformations in the superstructure. Solutions are obtained by representing the longitudinal bending moment distribution in series form and deriving analytical solutions for stresses and deflections. The amount of computation required is less than that for Chapman's method, but variations in section and foundation modulus cannot be incorporated. Neither can the boundary conditions at the ends be met, but in this case equilibrium is enforced by applied moments.

44 While all these methods are ingenious ways of investigating the complex problem, not one of them is capable of allowing for all the important design parameters and, moreover, are difficult and time consuming to apply. Consequently, superstructure analysis was an early candidate for the use of finite element methods. Paulling and Payer (1968) were among the first to demonstrate the application and showed that the only approximations necessary are those implicit in the use of a finite element process. Subsequent researchers, for example Mitchell (1976), have shown that to estimate the overall behaviour of the hull adequately it is important to model the bending stiffness of both the hull and the superstructure accurately (using beam elements) but for a good overall representation of in-plane stresses it is usually sufficient to include only membrane stiffness. However, if accurate local bending stresses are required, for example for fatigue analysis, then elements with bending capability are essential, and even then it is difficult to obtain realistic stiffener bending stresses without very detailed modelling. A means of obtaining a good approximate solution to the bending and shear stress distributions without modelling too much of the structure is presented by Smith and Chalmers (1987).

45 While these methods enable an existing superstructure to be analysed as a check on the stress levels, there is little information available to help the designer with synthesis. At the mid-length it is reasonable to use longitudinal stresses and lateral loads to estimate scantlings in the same way as is proposed for the hull deck and sides in Chapter 7. However, the end scantlings will be dominated by vertical and shear loads. As a first approximation it is suggested that a variation of the beam model could be used to estimate these loads by assuming that the superstructure is supported *only* on transverse bulkheads. Using the estimated bending moment distribution and variation in hull section modulus along the length from methods proposed in Chapters 3, 6 and 7, deflections at each supporting bulkhead can be estimated relative to a notional straight line through the ends of the superstructure. It is then possible to use simple beam theory to estimate the forces at the bulkheads to give the same relative deflections in the superstructure, assuming it to be a simple beam of constant section modulus.

46 These forces can then be used to design the superstructure ends and internal transverse bulkheads in the same way as for main transverse bulkheads (Chapter 9). Furthermore, they can be used to generate a shear force distribution which can then be used to estimate scantlings at the ends of the sides of the superstructure in the same way as for the shear strake described in Chapter 7. This process is probably rather conservative, but as it will always be advisable to undertake a final analysis using finite element methods, the scantlings may be refined at that stage.

Resistance to Nuclear Air Blast

47 The design procedures discussed above assume a superstructure which has to withstand normal environmental loads, albeit those suffered during warship operations. Some warships will be required to withstand the effects of nuclear air blast which adds a further complication. Estimation of air blast loads and time histories are described in Chapter 4 but some extra consideration of design principles is needed here, and a method of design based on work carried out at the Naval Construction Research Establishment (now DRA Dunfermline) in the early 1960s is presented.

48 The overriding principle in design for air blast resistance is that the superstructure exterior should be as clean and smooth as possible, with a minimum of re-entrants and with trihedrals given as wide an angle as possible. To that extent it is similar to designing for reduced radar cross section, but is particularly important because a re-entrant corner can increase the local incident pressure by at least a factor of *15*. Even if re-entrant corners are avoided, however, there will still be some pressure intensification due to interaction between superstructure blocks, and if they are closer than, say, the L/10 rule proposed in paragraph 19 it may be desirable to carry out shock tube tests on a model to identify and resolve local areas of pressure magnification.

49 As described in Chapter 4, there may be two levels of air blast pressure to which the structure must be designed, namely a lower level at which no loss of operational capability is acceptable, and a higher level at which the structure must remain safe and airtight although it may be distorted. Design of stiffened panels to withstand the lower level should probably be done elastically using the free field overpressure as if it were statically applied, but the method described below may be used in either case. The response to either pressure level can be assumed to be that due to a blast wave travelling parallel to the water surface, but the loading effects on vertical and horizontal structure will be different.

Structure Normal to the Blast Wave

50 Unless the weapon is very small (less than a kilotonne) the problem is simplified by assuming that the blast pressure curves illustrated in Chapter 4 (*Figures 4.3* to *4.5*) are each made up from two straight lines with, in this case, the peak pressure being the reflected pressure from *Figure 4.3*. The dynamic deformation can be formulated as a simple differential equation whose solution is of the form:

$$x_{max}/x_e = f\,[\{t_s/\sqrt{(W_e x_e)}\},\ P_c,\ P_{so}] \tag{8.5}$$

where x_{max} is the greatest deflection reached during loading, x_e is the maximum elastic deformation and the other parameters are defined as follows, making some approximations.

51 The effective weight W_e is a measure of the weight per unit area of structure being accelerated by the blast wave and is given by:

$$W_e = (W_P + W_f/s)/1.5 \tag{8.6}$$

where W_P is the weight per unit area of plating and W_f is the weight per unit length of stiffeners at spacing s.

52 The static collapse pressure p_c is assumed to be due to the collapse of the stiffeners and is given to a first approximation by:

$$p_c = 8\ (M_{p1} + M_{p2})/L^2 s \tag{8.7}$$

where M_{p1} and M_{p2} are the plastic hinge moments at the two ends of the stiffener of span L. It is usually sufficiently accurate to take the plastic hinge moments for the stiffeners alone about the point of attachment to the plate unless the plating is very light.

53 The maximum elastic deformation x_e is given by:

$$x_e = L^2\ (5M_{p1} - M_{p2})/48EI_c \tag{8.8}$$

where $M_{p1} \leqslant M_{p2}$ and I_c is the second moment of area of a stiffener with an effective breadth of plating equal to 50 times plate thickness.

54 The duration of the reflection and diffraction phase t_s is given in Chapter 4 and defined in *Figure 4.3*, while the incident overpressure P_{so} is the nominal free field value given in the requirements for the design. Provided that P_{so} is less than about 70 kPa, values of x_{max}/x_e can be taken from data sheets 18.82 to 18.84 for values of $t_s/\sqrt{(W_e x_e)}$, p_c and P_{so} interpolating as necessary. The maximum allowable value of x_{max} will depend on the contents of the superstructure; generally impact between the structure and any equipment inside should be prevented and a clearance of 100 mm after permanent set is probably needed to ensure that essential equipment continues to operate. Otherwise, to minimise the risk of rupture of structure, provided that conventional ductile steel is used, a deflection of 400 to 600 mm over a normal deck height should be acceptable.

Note that these data sheets are not non-dimensional and are presented in imperial units, that is, with pressure in lb/in², W_e *in* lb/ft² *and* x_e *in* inches. *To convert the parameter* $t_s/\sqrt{(W_e x_e)}$ *from* *metric units with* W_e *in* kg/m² *and* x_e *in* millimetres, *the metric value should be multiplied by a factor of* 11.14 *before it is used in the data sheets. Similarly, pressure in* kPa *should be multiplied by* 0.145 *to give* lb/in².

Structure Parallel to the Blast Wave

55 For weapons of significant size an open deck surface is effectively loaded by a suddenly applied constant pressure to the nominal incident overpressure P_{so}. Simplifying in a similar manner to the process above, but in this case using an energy equation, it can be shown that:

(8.9) $$x_{max}/x_e = p_c/\{2\,(p_c - P_{so})\}$$

As a first approximation p_c may be taken as 1.5 P_{so} giving x_{max} = 1.5 x_e.

56 For horizontal surfaces abreast higher superstructure varying pressure loading will occur ranging from the reflected pressure at the foot of the vertical surface to the free field overpressure at some distance away. For lack of better information it is recommended that an area of the horizontal structure equivalent to the area of the local vertical face should be designed to the higher reflected pressure.

Stiffening Direction

57 Maximum deflections are sensitive to stiffener size and span and relatively insensitive to plating thickness. Consequently, unless longitudinal stiffening is necessary from longitudinal strength considerations, a conventional superstructure with a longer span between transverse bulkheads than between decks can be designed more efficiently to resist air blast by using vertical stiffening only.

58 If orthogonal stiffening is used for any reason, then a good approximation to the collapse load is given by the sum of the collapse loads of the two sets of stiffeners taken separately. The calculation of x_e is more difficult, but a pessimistic assumption is to take the smaller of the values of x_e calculated for each set of stiffeners separately.

Detailed Analysis

59 As a final detailed analysis it will usually be desirable to carry out a dynamic time domain calculation at both design pressure levels using the dynamic capabilities of computer programs such as FABSTRAN described by Dow and Smith (1986) to ensure that the structure remains elastic at the lower level and does not collapse at the higher level. Insurance against local rupture is more difficult, and depends on providing a structure with no significant discontinuities of stiffness such as large steps in plating thickness or unsupported ends of stiffeners (which are bad practice anyway). This aspect is discussed in more detail in Chapter 15 in relation to resistance to underwater explosive loading.

Design Example

60 The following example is included to illustrate the most important aspects of the methods described above. It is based on the hull design example included earlier in this publication where the main ship dimensions and design loads are given (Chapter 7, paragraph 3). Note that the acceptance criteria used in this chapter are the same as those recommended for the hull and deck structure, and summarised from paragraph 90 onwards in Chapter 7. What will now be added to the structure of Chapter 7 is a single block of superstructure of one deck height and of relatively short length so that it would not initially have been taken as part of the hull girder. The arrangement is shown in *Figure 8.6* and is of length 40 m, breadth 10 m, height 3 m and the fore end is 30 m forward of amidships with the position of supporting main transverse bulkheads as shown in the figure. The holes in 1 and 2 deck shown in *Figure 7.7* will also be taken to penetrate 01 deck at its mid-length. Although it would not be true in practice, it will also be assumed that the hull section modulus and design shear force and bending moment are constant over the length of the superstructure and equal to those given or calculated in Chapter 7; this assumption much simplifies the data generation and in no way invalidates the demonstration of the procedure.

61 The first step in the design process is to estimate the superstructure efficiency at a number of critical sections. In this case the sections would be at amidships, at each internal bulkhead and at the mid-length of the superstructure, the first of these for the final design of the midship section and the last for the design of the most efficient section of the superstructure. As the process for each of the sections is the same, only one will be covered here and the mid-length section will be taken as typical as well as being the most heavily loaded.

62 At this stage the actual thickness of the superstructure side plating (t_s) is not known but from similar ships it will be assumed to be 8 mm (6.7 mm after deduction of tolerances); there is then sufficient data to calculate the deck flexibility factor ψ from equation 8.4. Noting that $C = 0.56$ from paragraph 33 and *Figure 8.5(a)*, and $K = 27.1$ from *Table 8.2*, ψ is then equal to 225. For the mid-length section L_s is 40 m (note that had the midship section been chosen L_s would be 20 m as explained in paragraph 35) and so $L_s/d_s = 13.3$ and from data sheet 18.41 $\eta_{so} = 0.44$.

63 From the dimensions given above the value of $B_s/d_s = 3.33$ and so from data sheet 18.42 $\eta_{s1} = 0.52$. From equation 8.2 the value of d_{na}/D_{na} is estimated to be 0.45 (note $B^* = 12$ m and $B_s^* = 7$ m as defined in paragraph 31) so that from data sheet 18.43 $\eta_{s2} = 0.51$. If this value of efficiency is used instead of η_{ss} in equation 8.3 (as suggested in paragraph 36) then A_s/A_h is estimated to be 0.17 and from data sheet 18.44 $\eta_{ss} = 0.54$. This low value, incidentally, confirms

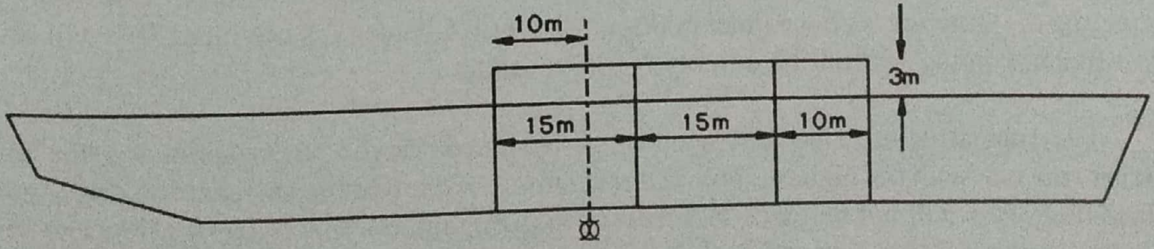

Figure 8.6 Superstructure Arrangement

the decision implicitly taken that the superstructure is not efficient enough to be used as part of the main hull girder, when an efficiency of at least 80% would be desirable.

64 With a value of efficiency estimated it is possible to use equation 8.1 to estimate the stresses in the structure. However, it should be noted that the values of z_{100} and I_{100} can be calculated from the estimated ratios above as follows:

(8.10) $$z_{100} = D_{na}\{1 - (A_s/A_h)(d_{na}/D_{na})\}/\{1 + (A_s/A_h)\}$$

(8.11) $$I_{100} = I_o + A_h D^2_{na}\{1 + (A_s/A_h)(d_{na}/D_{na})^2 - (1 + A_s/A_h)(z_{100}/D_{na})^2\}$$

From Chapter 7 it will be seen that $I_o = 13.65$ m^4, $A_h = 0.953$ m^2 and $D_{na} = 5.08$ m so z_{100} is now estimated to be 4.01 m and I_{100} to be 21.16 m^4. For the design sagging bending moment of 400 MN.m it follows from equations 8.1 that $\sigma_d = 71.6$ MPa and $\sigma_r = 109.4$ MPa.

65 There is now enough loading information to create a design for 01 deck, noting also that from Chapter 3 an exposed deck at this level must be designed to withstand a green sea pressure of 25 kPa with a margin of 20% on yield (Chapter 7). This pressure is not continuous so the in-plane load and the lateral load can be treated independently; however, as the in-plane load is low it is likely that the lateral load will dominate and so should be used in the initial synthesis.

66 If the same beam spacing as on 1 deck of 2.5 m is assumed, together with a longitudinal stiffener spacing of 1.0 m then, for the applied pressure and allowable stress, a minimum section modulus of stiffener and associated plate of 87.1 cm^3 is required. Reference to data sheets 18.30 to 18.36 indicates that the smallest Tee section to satisfy the requirement is a type 3 with any reasonable thickness of plating. If a maximum b/t of about 90 is accepted (see Chapter 7, paragraph 5) the minimum weight structure can be shown to be when b is less than 500 mm and t less than 7 mm. While minimum weight at this height above the centre of gravity is important, such a structure would be difficult to build and a wider spacing is desirable; to give an integer number of longitudinal stiffeners in the 3.5 m transverse span while providing an in-plane strength which is not unduly high, a good compromise can be shown to be with four type 3 stiffeners on 8 mm nominal thickness plate, giving b = 875 mm and b/t = 131 (note that there is no particular merit in having the same longitudinal stiffener spacing in 01 deck as in 1 deck). This is a very high value of b/t, but although the in-plane collapse strength is approximately 114 MPa (using the methods of Chapter 7) and so the structure is inefficient, it is still strong enough to withstand the estimated applied stress of 71.6 MPa. At the same time the maximum bending stress under 25 kPa pressure is 141.3 MPa which, for an occasionally load, can be treated independently from the in-plane load, and which is then well within the allowable stress of 80% of yield. Comparing the structure with the inner bottom in the hull (Chapter 7, paragraph 50) it will be seen that stiffener tripping will not be a likely mode of failure.

67 The superstructure side will need to be designed for the stress applied at the lowest stiffener (the one with the highest applied direct stress). Although the stiffener spacing is not yet defined this stress will not be much less than σ_r in paragraph 64, that is 109.4 MPa. The design green sea pressure is the same as for 01 deck and so type 3 Tees will still be needed, but the value of b/t must be less because of the higher applied direct stress. Additionally, because there will be significant shear stress in the structure the margin between average in-plane collapse stress and applied stress must be higher, as described in Chapter 7, paragraph 61. The reduced b/t is probably best arrived at by a combination of smaller b and larger t, and keeping to an integer number of stiffeners in the 3 m height, a combination of 750 mm spacing on 10 mm plate gives b/t = 86 and an average collapse stress of 137.2 MPa, which is comfortably above the likely applied stress.

68 Considering shear, the superstructure, except very near the ends, will be much more efficient than in bending provided that the rules for proper integration have been followed. Consequently, it is reasonable to apply equation 7.13 directly without any allowance for superstructure efficiency and without being too conservative. Taking the structure so far defined, the shear stress on the lowest side stiffener will be 37.6 MPa while in the middle of the lowest plate panel it will be 39.1 MPa. Again using the procedures described in Chapter 7 it can be shown that the critical shear buckling stress in the plate τ_{sc} is 144.8 MPa. Both of these are easily acceptable against the applied stress, but the latter, from equation 7.14, leads to a margin of 1.07 being required between in-plane applied and average collapse stress. Knowing now where the stiffener is, the direct applied stress can be estimated using the idealised distribution shown in *Figure 8.3* and is 100.0 MPa, which has a margin of 1.23 below the average collapse stress, and so the structure is still satisfactory.

69 The scantlings now arrived at are, in 01 deck, 8 mm plate with type 3 Tee stiffeners at 875 mm spacing, and in the superstructure side, 10 mm plate with the same stiffeners at 750 mm spacing. It remains, therefore, to recalculate the parameters quoted in paragraph 31 for a better estimate of superstructure efficiency. The cross sectional area of the superstructure is 0.122 m^2 and d_{na} = 2.23 m, while the second moment of area of the superstructure about 1 deck is 0.710 m^4. z_{100} is therefore actually 4.25 , and I_{100} is 19.55 m^4 compared with the initial estimated values of 4.01 and 21.16 respectively. This implies that the prediction method in paragraph 31 rather overestimates the superstructure weight and contribution to the hull girder, but as such it will be conservative and at least will give a reasonable starting point. A recalculation of the superstructure efficiency shows it to be 0.48 compared with 0.54 previously, reflecting the lighter scantlings. However, the applied direct stresses will now be 70.4 MPa in 01 deck (compared with 71.6 which is not significantly different so the original structure can remain unchanged) and 119.6 MPa in 1 deck (compared with 109.4). This latter figure leads to a higher stress in the superstructure side while the lower value of I_{100} leads to a higher applied shear stress. The required margin for direct stress is now 1.09 but the actual margin is 1.15 so the structure is still adequate.

70 It would be theoretically possible now to iterate again to reduce the scantlings of 1 deck in the region of the mid-length of the superstructure, because the direct hull bending stress is lower than originally calculated. However, for the relatively short superstructure used in this demonstration the structure of 1 deck is overdesigned over only a very short length because the superstructure efficiency drops away very rapidly from the maximum, it is in fact only 19% at amidships (that is, at the quarter point of the superstructure) so the advantage in weight reduction from a lighter 1 deck would be very small and would not justify the increased analytical effort and constructional complications.

71 Similar calculations to those described above would be carried out at the other important sections of the superstructure so as to refine the scantlings. The direct stresses due to hull bending will clearly reduce towards the ends but the pressure loads will remain constant along the length and shear stresses will increase due to the compatibility forces. Consequently it is unlikely that there will be much scope for reducing the scantlings and any consideration of structural refinement may best be left until a more detailed analysis is completed as discussed in paragraph 74.

72 The increased shear stresses towards the ends can be estimated as proposed in paragraph 45, that is assuming the superstructure to be a uniform beam supported only at the transverse bulkheads and constrained to bend to the curvature of the main hull. From the assumptions of uniform bending moment and hull stiffness stated in paragraph 60 it can be shown that at the forward of the two internal bulkhead positions the deflection relative to a straight line through the ends of the superstructure is 42.5 mm while at the after internal bulkhead it is 53.1. It is then a simple matter to analyse the uniform beam shown in Figure 8.7, which has an EI value of 10.88 GN.m^2 derived from the scantlings above (assuming all structure to be fully effective), to obtain values for the forces as follows (the signs are only significant relatively):

$F_0 = 249$ kN $\quad F_1 = -264$ kN
$F_2 = -337$ kN $\quad F_3 = 352$ kN

73 The greatest shear force is clearly 352 kN at the forward end, and if this is spread over the two superstructure sides (of total area 0.052 m) assuming a parabolic distribution of shear stress (assumes zero stress at the top and bottom and is therefore conservative) a maximum stress of 10.1 MPa may be derived. This a fairly low value when compared with the material strength or with the shear stress due to hull bending at the superstructure mid-length, and so there will be no difficult in providing adequate scantlings, probably maintaining scantlings constant over the superstructure length as assumed in the uniform beam. However, the method does indicate the sensitivity of vertical forces to superstructure bending stiffness and, in particular, if the structure were to be made much stiffer at the ends the forces would be very much higher making it difficult to design adequate scantlings.

74 The forces derived above may also be used in the design of bulkheads, although clearly the load is shared between the longitudinal and transverse structure. However, as a first approximation the forces can be used directly and the transverse structure may then be designed as described for main transverse bulkheads in Chapter 9.

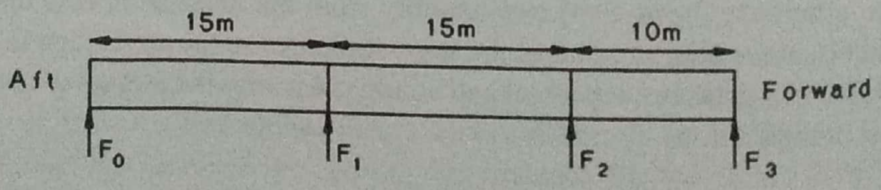

Figure 8.7 The Superstructure as a Simple Beam

Final Analysis

75 Finally, when the structural design is complete it will be necessary to undertake a more detailed finite element analysis as discussed in paragraph 44 and 46. Such an analysis need not be especially detailed provided that it models the bending stiffness of the hull and superstructure reasonably accurately, and a computer program such as MAESTRO described by Hughes (1983) and discussed in Chapter 17, which is a coarse mesh program with a good ship based preprocessing facility, will be sufficient. (Note that MAESTRO is not yet suitable for analysis of FRP structures and a more detailed finite element program will be necessary in such a case.) It will also be necessary at this stage to include all holes and other discontinuities in the superstructure (and in all other structure) so that a good understanding of the basic stress pattern can be obtained, and the structure refined accordingly. Areas of local high stress can be identified as candidates for more detailed analysis, in particular to avoid fatigue failures as described in Chapter 13.